Simulations of Marine Methane Cycle During Early Global Warming

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The Arctic Ocean contains vast amounts of methane clathrates embedded in continental shelf sediments. As the ocean warms due to climate change, it is possible that they could become unstable and release large amounts of methane gas into the water. This release could have a significant effect on marine biogeochemistry and atmospheric chemistry. Our simulations of sea floor methane release in a global ocean circulation model show that approximately 1% of the released methane could reach the atmosphere, and oxidation by marine bacteria could significantly change ocean pH and reduce dissolved oxygen levels to dangerously low levels in some regions in the Arctic.

Methane is a greenhouse gas. Due to its infrared absorption bands, each molecule of methane can cause almost thirty times as much warming as a molecule of carbon dioxide (CO_2). Although the ocean of today makes only a small contribution to the amount of atmospheric methane, this could change if the climate warms. For example, if the sea floor warms over the next few decades due to increasing ocean temperatures, methane hydrate clathrates (a solid compound in which methane is physically trapped in the crystal lattice of water ice), located on the upper continental shelf, could destabilize. This would result in methane percolation into the overlying ocean water. Some of the gas would reach the surface of the ocean and get transferred into the atmosphere. The Arctic Ocean harbors a significant fraction of the global methane hydrate reservoir because it is cold and relatively shallow. Regional expanses of sediment containing clathrate are likely to warm quickly under climate change, due to their close communication with ocean water masses, which are showing temperature increases. Clathrates are already emitting from perturbed bottom deposits in some parts of the high latitude north. Current global climate change models do not include these effects on methane release from the ocean floor and continental margins.

We made the first generation simulations of pathways by which methane will influence, and in turn be controlled by, marine geochemistry and biology as it makes its way from sediments through overlying seawater. Our goal was to capture geochemical behaviors during the onset of an upcoming warming destabilization era. As their framework, the calculations take a one-degree resolution, global Parallel Ocean Program (POP) configuration used for simulating ocean circulation, enhanced with marine ecodynamics, biogeochemistry, and dissolved trace gas chemistry (i.e., methane) transport. A key step in the present, large-scale hydrate destabilization calculations is adoption of emissions from a LBNL model of multi-phase porous flow from the sediment. This flow model has recently been driven by global warming-type temperature increases and produces rapid methane flow from the sea bed, beginning relatively quickly in geological terms (within a decade or so).

As the methane is injected into the ocean, it is transported into the interior and toward the surface by a number of physical processes. In addition, several types of methanotroph proteobacteria are capable of breaking down methane in solution, which can reduce the amount of methane released into the atmosphere. These bacteria require nutrients and trace metals for this function. Therefore we examined the bacteria's specialized resource requirements with marine trace element availability in regions of early clathrate decomposition. Oxygen, nitrogen, and trace metals are potential limiting reagents for the methanotrophs during consumption of methane. Interplay between these bacteria and other members of the ecosystem has the potential for even more pervasive changes to high latitude marine biogeochemistry. For example, changes

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in the oceanic dissolved inorganic carbon concentrations could alter the local pH. It may also be possible for dissolved oxygen levels to drop to low enough levels that thresholds for detrimental biotic effects can readily be crossed.

We conclude that during global warming several deleterious effects could occur as a result of methane release. It is possible that either (1) hydrate-derived methane would be rapidly removed from seawater, causing significant changes to pH and oxygen levels, or (2) the availability of certain resources would fall short for the methanotrophic bacteria, allowing the methane to reach the atmosphere, which would serve as a positive feedback to global warming. Simulations of this sort will provide robust results as data improves for the global distribution of geochemical sources and biotic consumers. We believe that this will require extensive laboratory work and field studies of the interaction of methane with bacterial ecosystems. Obtaining data is essential in order to determine the impact of global warming on methane release from clathrates. Even the greatest known present-day methane releases, such as mud volcanoes, do not generate plumes of the size predicted by these climate change simulations (see Fig. 1).

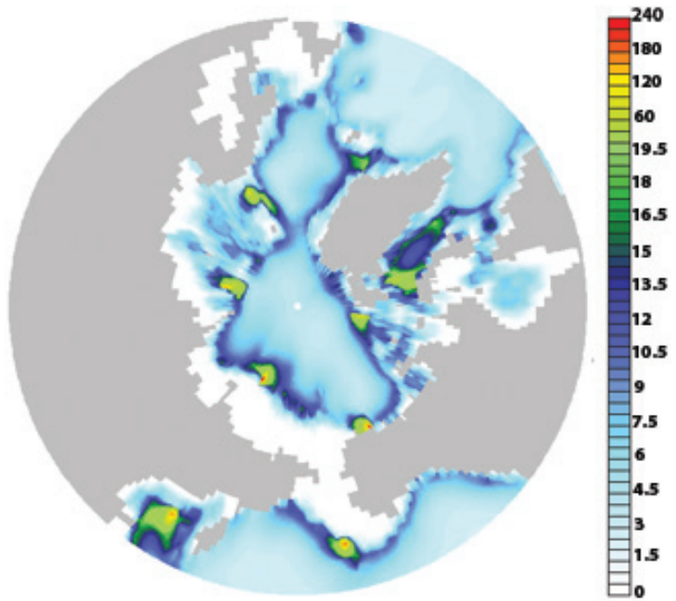

Fig. 1. Vertical integral of methane concentration (millimole/m²) after 40 years of model simulation (viewed looking down at the North Pole). Eight locations on the ocean floor at a depth of 300 meters were selected as sites of methane injection from the underlying sediment.

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